Plateau PEMS emission characteristics analysis of heavy-duty diesel vehicles with different technical routes

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Abstract: Real driving emission characteristics of heavy-duty diesel vehicles with different technical routes were conducted by portable emission measurement system (PEMS) tests at different altitudes of 1400 meter and 2300 meter. Results show that the use of EGR will lead to increased particulate matter emissions but has little effect of NOx emissions. The EGR application exhibits a large effect on the PN emission but a little effect on NOx emission. PN emissions were strongly correlated with engine load during the PEMS test. The higher the engine load, the higher the PN emissions even at lower altitudes. There are large differences in PEMS test results even at the same altitude.

1. Introduction

With the rapid increase in vehicle ownership, the environmental problems have also attracted more and more attention. The exhaust pollution of diesel vehicles, especially heavy-duty diesel vehicles, is extremely serious. The China Mobile Source Environmental Management Annual Report (2021) shows that the nitrogen oxides (NOx) and particulate matter (PM) emissions of diesel vehicles account for more than 80% and 90% of the total vehicle emission. In 2018, China VI emission standard of heavy-duty diesel vehicle has been issued, and a new test method named PEMS (Portable Emission Measurement System) test was introduced to evaluate the real driving emissions. The PEMS test requires vehicles to meet the emission limit requirements at different altitudes, of which the altitude requirement for stage 6a is 1700 meters, and the altitude requirement for stage 6b is 2400 meters.

Due to the low atmospheric pressure and low air density, the airflow sucked into the engine cylinder is reduced when vehicle drives at plateau region, resulting in an imperfect combustion and an increase of the fuel consumption as well as pollutants emission deterioration [3]. Previous research has focused on exploring the effect of altitude on performance and emissions of engines rather than vehicles. For example, Ghazikhani et al [4] found that the power and torque of turbocharged diesel engines decreased with the increase of altitude. Meanwhile the thermal load increased, which challenges the cooling capability of turbocharger and engine. Zhao et al [5] and Ceballos et al [6] found that the power, fuel consumption and emissions of turbocharged inter-cooler diesel engines have deteriorated to a certain extent as the altitude rises.

Several real driving emission research has been published for both light-duty vehicles and heavy-duty vehicles [7-9]. However, they seldom focus on emissions under plateaus environment for heavy-duty vehicles. In this context, two heavy-duty diesel vehicles with different technical route were selected and carried out the PEMS tests at different plateau regions to investigate the real driving emission characteristics.

2. Experiment

2.1 Vehicles and equipment

Two main technical routes were adopted for heavy-duty diesel vehicles to meet the China VI emission standard, which named Exhaust Gas Re-circulation (EGR) route and NO EGR route [10]. The emission control system of EGR route includes EGR, Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF), Selective Catalytic Reduction (SCR) and Ammonia Slip Catalyst (ASC), while the emission control system of NO EGR route only includes DOC, DPF, SCR and ASC. The two test vehicles selected in this paper adopt these two technical routes respectively. The main technical parameters of the test vehicle are shown in Table 1.

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Table 1 Main technical parameters of tested vehicles

Parameter	Vehicle 1	Vehicle 2
Vehicle type	N2	N3
Total mass/kg	8500	12000
Curb mass/kg	3690	5680
Rated power/kW	115	210
Maximum torque/Nm	500	1020
Emission Control Technology Route	DOC+DPF+ SCR+ASC	EGR+DOC+DP F+SCR+ASC

AVL MOVE PEMS was used for tests. The PEMS system includes exhaust gaseous pollutant analysis system (GAS PEMS), exhaust particulate matter analysis system (PN PEMS), exhaust gas flow meter (EFM), global positioning system (GPS), temperature and humidity instrument, OBD recorder and other equipment.

2.2 Plateaus test routes and environment

The test routes were selected in three different cities with two different altitudes. The time percentages of test routes for Vehicle 1 are 45% of urban part, 25% rural part and 30% motorway part, while the time percentages of test routes for Vehicle 2 includes 20% of urban part, 25% rural part and 55% motorway part. Figure 1 shows the vehicle speed data for one of routes. The loading percentages of all tests are set to 50%.

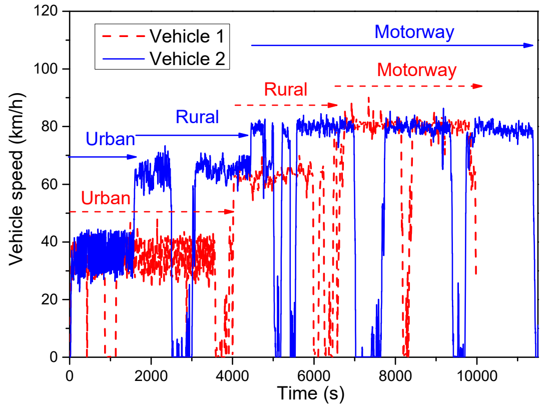

Figure 1 Vehicle speed curve schematic during the PEMS test

The test routes details and the environment condition during the route can be seen in Table 2. The average altitude of test route 1 (TR1) is about 1430 meter under the test environment of about 23 °C temperature and RH88% humidity. While the average altitude of both test route 2 and 3 (TR2 and TR 3) are around 2300 meter. TR 2 has a relatively high temperature but a low humidity. Additionally, the test route of vehicle 2 has a relatively high vehicle speed and running distance.

Table 2 Test routes details and the environment condition

Test Routes	Details	Vehicle 1	Vehicle 2
TR1	Average altitude/m	1434.9	1438.5
	Average environmental temperature/°C	23.5	22.4
	Average environmental humidity/RH%	88.1	88.0
	Average vehicle speed/km/h	52.0	65.7
	Route total distance/km	176.7	253.2
TR2	Average altitude/m	2314.9	2314.7
	Average environmental temperature/°C	29.9	29.9
	Average environmental humidity/RH%	46.5	46.0
	Average vehicle speed/km/h	50.8	62.3
	Route total distance/km	138.7	285.2
TR3	Average altitude/m	2347.1	2328.9
	Average environmental temperature/°C	17.1	16.7
	Average environmental humidity/RH%	59.2	60.8
	Average vehicle speed/km/h	51.5	64.4
	Route total distance/km	168.1	242.2

3. Results and Discussions

3.1 Brake specific emission of vehicles with different technical routes

The brake specific emissions of these two vehicles at different altitudes are shown in Figure 2. For vehicle 1, the NOx brake specific emissions for the three test routes were 0.17, 0.15 and 0.24 g/kW.h, respectively. The PN brake specific emissions were 0.35×10^{12}, 0.11×10^{12} and 0.099×10^{12} # /kW.h, respectively. For vehicle 2, the NOx brake specific emissions were 0.16, 0.2 and 0.14 g/kW.h for RT1, RT2 and RT3, respectively. while the PN brake specific emissions were 0.53×10^{12}, 0.43×10^{12} and 0.14×10^{12} # /kW.h. It can be seen that the test results of the two vehicles can meet the limitation requirements of China VI emission standard of heavy-duty diesel vehicle. The NOx emission did not exhibit an unifying trend with increasing altitude. While the PN emission decrease as the altitude increases. The PN emissions are reduced by 68.6%

and 71.7% for vehicle 1 and 18.9% and 73.6% for vehicle 2 when increasing the altitude from 1400 meter to 2400 meter. For the same altitude like RT2 and RT3, the NOx and PN emission show different trends. The NOx emission is increased by 60% for vehicle 1 but reduced by 30% for vehicle 2. The PN emission is decreased by 10% and 67.4 for vehicle 1 and vehicle 2, respectively.
Moreover, the PN emission of vehicle 1 with no EGR route is significantly lower than that of vehicle 2 with EGR route, while the NOx emission of vehicle 1 is slightly higher than that of vehicle 2. For vehicle 2 that adopts the EGR, the combustion will deteriorate after the introduction of EGR, which resulting in an increase in particulate matter emissions, and the deterioration will intensify with increasing altitude. By contrast, NOx emissions are the combined result of generation and elimination [11-12]. The introduction of EGR will help to reduce the generation of NOx due to a lower in-cylinder temperature, so the NOx emission shows a soft improvement for vehicle 2.

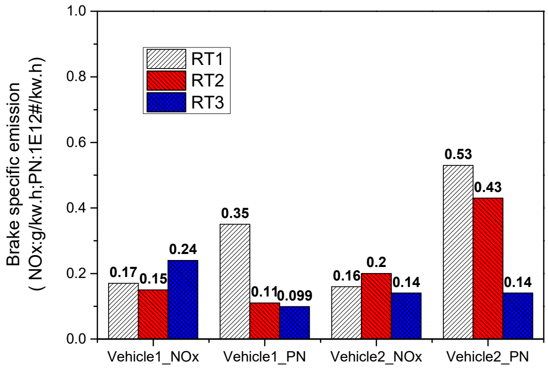

Figure 2 Brake specific emissions at different altitudes

3.2 Transient emission characteristics of vehicles with different technical routes

Figure 3 shows transient parameters including NOx and PN emission, vehicle speed and exhaust temperature of vehicle 1 at different routes. As can be seen from Figure 3, the peak of NOx mainly occurs when driving in urban part, corresponding to Regions 1 and 2. There is also sporadic peak distribution of NOx emission during the rural part and motorway part. These sporadic peaks generally appear accompanied by low exhaust temperature or an abrupt acceleration. The peak of PN emission mainly occurs when driving in rural part and motorway part. As altitude increases, the PN emission peak height and frequency significantly decreased.

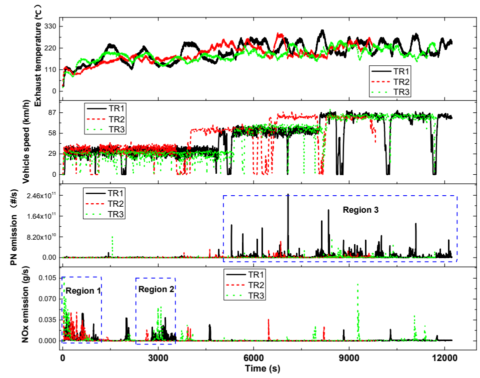

Figure 3 Transient emission characteristics at different technical routes for vehicle 1

Figure 4 shows transient parameters including NOx and PN emission, vehicle speed and exhaust temperature of vehicle 2 at different routes. As can be seen from Figure 4, the peak of NOx mainly occurs when driving in urban part for TR2, which is similar to vehicle 1. By contrast, the NOx emission peak distribution appears more frequently during the rural part and motorway part. It is believed that the frequently acceleration and deceleration are responsible for the NOx emission increase. PN emission mostly distributed in the motorway part, and the increased altitude reduced the PN emission.

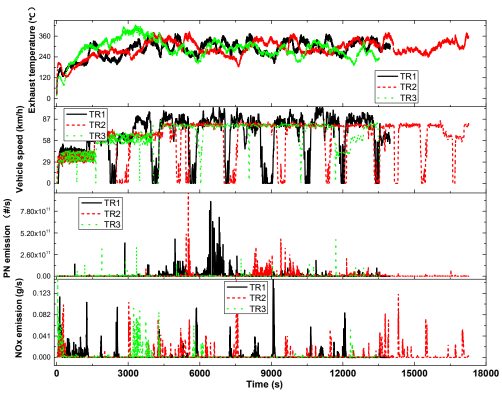

Figure 4 Transient emission characteristics at different technical routes for vehicle 2

NOx emissions are the combined result of generation and elimination. The generation is closely related to in-cylinder combustion and engine operating conditions, while the elimination is closely related to exhaust temperature and SCR catalytic efficiency. The average exhaust temperature is shown in the Figure 5. For vehicle 1, the average exhaust temperature of three routes is 202.5, 189.4 and 185.3°C, respectively. The exhaust temperature has a slight decrease as the altitude increases. The average exhaust temperature of three routes is 286.5, 290.2 and 287°C for vehicle 2, respectively, showing minor differences with the increase of altitude. The combustion speed will be reduced after the introduction of the EGR gas, resulting in an increase in the post-combustion heat and exhaust temperature. The average exhaust temperature of vehicle 1 is obviously lower than vehicle 2, but the NOx emission of vehicle 1 is still comparable to vehicle 2, indicating the no EGR route has a higher SCR catalytic efficiency.

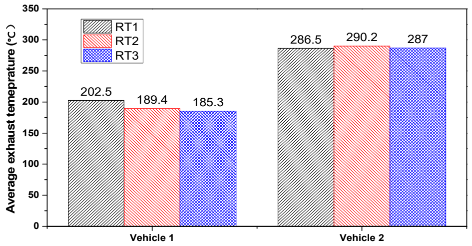

Figure 5 Average exhaust temperature during the different routes

PN emission is strong related to the engine load [13-14]. Generally, the engine load will reduce as altitude increases at same engine conditions. During the real driving test, the engine load is dependent on the test route and the vehicle loading. For the same vehicle, the loading of each test is the same, so the engine power is mostly decided by test route. The transient power point distribution of two vehicles at TR1 and TR2 can be seen in Figures 6 and 7. The transient power range is narrowed when the altitude increases for both vehicles. The high load at low engine speed and high engine speed areas of TR1 is smaller than TR2, and the average power of TR1 is higher than TR2. Therefore, the PN emission of TR2 is much higher than TR1.

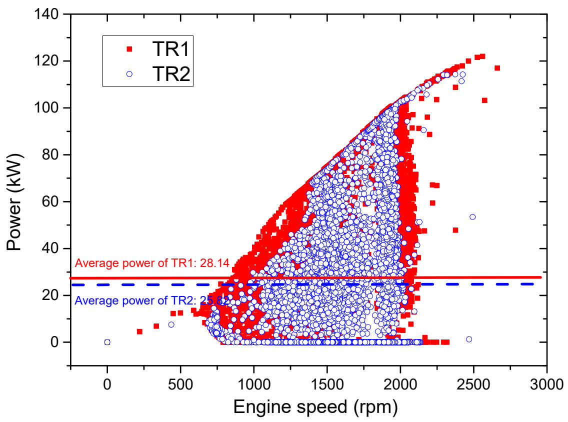

Figure 6 Power distribution of vehicle 1

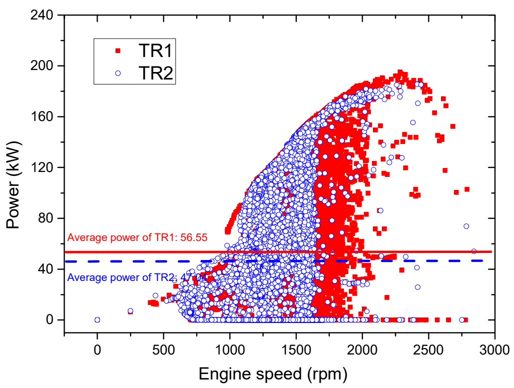

Figure 7 Power distribution of vehicle 2

4. Conclusion

Compared with the EGR route, the use of EGR will lead to increased particulate matter emissions but has little effect of NOx emissions.
(2) An increase in altitude does not necessarily lead to an increase in particulate matter emission. PN emissions were strongly correlated with engine load during the PEMS test. The higher the engine load, the higher the PN emissions even at lower altitudes.
(3) There are large differences in PEMS test results even at the same altitude. When analyzing the PEMS test data, it is necessary to fully consider the influence of altitude factors, driving conditions, road conditions, and engine calibration strategies on the PEMS results.

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